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Three-dimensional pelvimetry by computed tomography

Pelvimetria tridimensionale mediante tomografia computerizzata

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Abstract

Purpose. This study was undertaken to assess the agreement of computed tomography (CT) pelvimetry with different postprocessing techniques.

Materials and methods. CT data sets of 25 patients were retrospectively analysed. There were no CT examinations performed solely for pelvimetry, and there was no radiation exposure for study purposes. Six pelvimetric measurements were obtained by two independent observers in four data sets of each patient, i.e. on biplanar topograms, multiplanar reconstructions of 1-mm slices, volume-rendered images of the same data and volume-rendered images based on 5-mm-thick images. Interobserver agreement and variability were determined by Bland-Altman analysis. A human skeleton was also scanned and measured with the same techniques and by ruler as reference.

Results. With a correlation coefficient of 0.98, interobserver agreement was best for assessing 3D volume-rendered images reconstructed from 1-mm-thick slices. Interobserver variability was very good for sagittal outlet and midpelvic diameter, transverse inlet diameter and obstetric conjugate (correlation coefficients 0.96–0.99) but limited for intertuberous and interspinous distance. CT and ruler measurements of the skeleton showed excellent agreement.

Conclusions. Pelvimetry can be obtained with low interobserver variability on 3D volume-rendered CT reconstructions. Thus, CT pelvimetry is suitable to gain exact knowledge of pelvic anatomy to identify relevant parameters for dystocia in retrospective studies.

Abstract

Obiettivo. *Valutare la concordanza della pelvimetria-TC con differenti tecniche di post-processing.*

Materiali e metodi. *Sono stati analizzati retrospettivamente i dati TC di 25 pazienti. Non c'erano esami TC eseguiti esclusivamente per la pelvimetria, e non c'è stata esposizione alle radiazioni a soli fini di studio. Sono state ottenute 6 misurazioni pelvimetriche da due osservatori indipendenti in quattro data sets per ogni paziente, cioè topogrammi in due proiezioni, ricostruzioni multiplanari con scansioni dello spessore di 1 mm, immagini volumetriche degli stessi dati ed immagini volumetriche basate su scansioni dello spessore di 5 mm. La variabilità e la concordanza interosservatore sono state determinate secondo l'analisi Bland-Altman. E' stato analizzato e misurato con le stesse tecniche anche uno scheletro umano ed è stato preso come modello di riferimento.*

Risultati. *Con un coefficiente di correlazione di 0,98, la concordanza tra gli osservatori è stata migliore nella valutazione delle immagini volumetriche tridimensionali ricostruite da scansioni dello spessore di 1 mm. La variabilità interosservatore è stata molto buona per il diametro sagittale esterno e per il diametro intermedio della pelvi, per il diametro dell'inserzione trasversa e per la coniugata ostetrica (coefficiente di correlazione 0,96–0,99), ma limitata per la distanza tra le tuberosità e tra le spine ischiatiche. C'è stata una concordanza eccellente tra la TC e le misurazioni dello scheletro.*

Conclusioni. *La pelvimetria può essere ottenuta con una bassa variabilità interosservatore su ricostruzioni TC volumetriche tridimensionali. Pertanto, la pelvimetria-TC è*

Keywords CT-Pelvimetry · Cephalopelvic disproportion · Dystocia · Interobserver variability

adatta ad acquisire l'esatta conoscenza dell'anatomia pelvica per identificare i parametri rilevanti per distocia negli studi retrospettivi.

Parole chiave *Pelvimetria-TC · Sproporzione cefalo-pelvica · Distocia · Variabilità interosservatore*

Introduction

About two thirds of all caesarean sections are performed due to dystocia or are indirectly related to cephalopelvic disproportion because they are scheduled for elective caesarean after cephalopelvic disproportion at first delivery [1]. Cephalopelvic disproportion should be diagnosed when there is an adequately dilated cervix and sufficient contractions of the uterus but the fetal head does not descend into the birth canal [2]. Since this strict definition was applied, the rate of caesarean sections has dropped, but the incidence of prolonged and painful births has increased. The need for a reliable method to detect women at risk for dystocia has been recognised since the eighteenth century, and various approaches to pelvimetry have been used to identify small pelvis as indication for caesarean section. However, imaging modalities have lost importance in diagnosing a cephalopelvic disproportion, as results seemed to be of little clinical value for obstetricians. In fact, diagnostic accuracy in predicting dystocia is so weak that pelvimetry has been abandoned at most centres. Remaining current clinical indications include breech presentation and suspicion of cephalopelvic disproportion.

Magnetic resonance imaging (MRI) provides the possibility of obtaining arbitrary imaging planes of the pelvis and the fetus itself [3]. Conventional X-ray and CT pelvimetry have been largely abandoned since MRI pelvimetry became available, as exposure to ionising radiation, especially of the foetus, can be avoided [3–10]. In practical clinical application, MRI pelvimetry has shown to have some disadvantages, most importantly the need to correctly acquire the images in the exact plane. The technicians who routinely acquire the data frequently lack experience with pelvimetry, and an inaccurate planning of the sequences can result in gross measurement errors.

This problem can be overcome in CT with its continuous Z-axis coverage and the excellent postprocessing possibilities. It might therefore offer a reliable, high-quality pelvimetry and render the method clinically usable.

The aim of this study was to evaluate different methods of image acquisition and reconstruction and postprocessing approaches for CT pelvimetry to analyse their interobserver variability. The results should be useful to identify the postprocessing method with the best reproducibility and to estimate the required radiation exposure for low-dose exams. The study can also indicate necessary slice thickness for pelvimetry on previously existing CT scans, either to perform measurements for an individual patient or to retrospectively evaluate pelvimetric measurements of large patient groups for study purposes.

Materials and methods

Available CT Data

CT pelvimetry was performed in 25 female patients based on CT data that had been acquired in routine clinical care. The retrospective evaluation is warranted by the university's ethics committee guidelines and adhered to the World Medical Association Declaration of Helsinki. CT data sets of 15 consecutive women referred for abdominal CT postpartum in 2007 had been obtained on 64-slice CT scanners (Somatom Sensation 64 or Somatom Definition, Siemens, Forchheim, Germany) with 0.6-mm collimation at 120 kVp tube potential and 250 mAs reference tube current time product with dose modulation. The image data stored in the hospital's picture archiving and communication system (PACS) archive were retrospectively used for pelvimetry.

Additionally, pelvimetric measurements were acquired in CT data sets of ten women with known multiple myeloma who had undergone low-dose CT to screen for osteolysis and additionally had had a normal routine abdominal CT scan for other reasons within the last 2 years. The routine scans had been obtained with the routine parameters given above, whereas the low-dose scans had been acquired with a reduced tube current of 83 reference mAs. A human cadaver skeleton was also scanned with the mentioned normal and low-dose protocols to validate CT-pelvimetric measurements, with manual measurements by ruler as external reference.

The images were reconstructed at 1- and 5-mm slice thickness and equal increment with a standard medium–soft convolution kernel (B30). The images of the skeleton were also reconstructed at 1- and 5-mm slice thickness. Radiation dose was calculated for each exam based on the CT dose index (CTDI) and the scan length, which are represented in

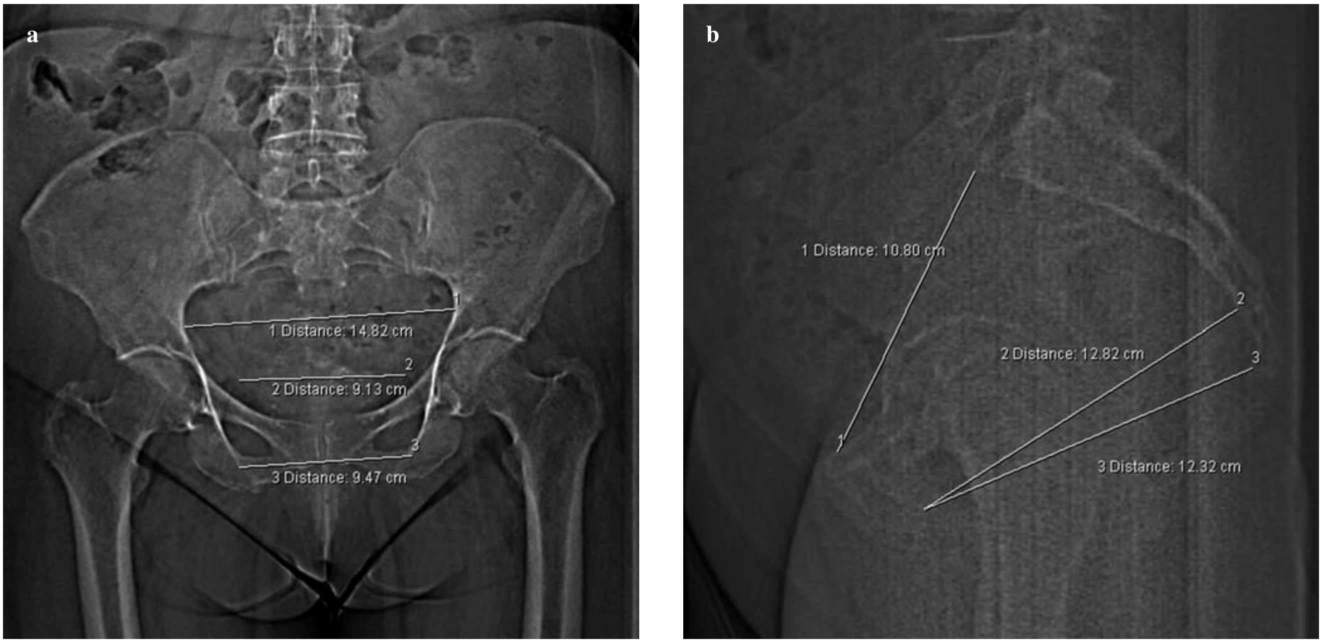

Fig. 1a Anteroposterior topogram. *Lines* indicate transverse inlet diameter, interspinous distance and intertuberous distance (cranial to caudal). **b** Lateral topogram. *Lines* indicate obstetric conjugate, sagittal midpelvic diameter and sagittal outlet.

Fig. 1a *Topogramma antero-posteriore. Le linee indicano il diametro traverso interno, la distanza interspinosa e la distanza tra le tuberosità (in senso cranio-caudale).* ***b*** *Topogramma laterale. Le linee indicano la coniugata ostetrica, il diametro intermedio della pelvi e il diametro sagittale esterno.*

the dose-length product (DLP). Values were available from patient protocols, which are saved in the PACS archive along with the image data according to legal requirements. The equivalent dose can be calculated from the DLP with a conversion factor of 0.017 mSv/mGy*cm for the pelvis [11].

Pelvimetry

Based on these images, pelvimetry was performed retrospectively by two independent blinded radiologists on a 3D workstation (Siemens Multi-Modality Workplace, Siemens, Forchheim, Germany) using topograms, multiplanar reconstructions and volume-rendered images. Obstetric conjugate, transverse diameter, interspinous distance, sagittal midpelvic diameter, intertuberous distance and sagittal outlet were measured in each data set using four different approaches. First, transverse measurements were acquired on the anteroposterior topogram (Fig. 1a). To simulate a lateral topogram, which had not been scanned in our patients, we additionally reconstructed a 35-cm-thick sagittal slice from the 1-mm slices, which strongly resembled a lateral projection image (Fig. 1b). The sagittal measurements were taken on this reconstructed image. In another approach, 2D multiplanar reconstructions were performed on 1-mm slices. To measure the transverse inlet diameter, the plane was adjusted to a para-axial position so that the upper rim of the pelvic inlet was displayed in an oval shape (Fig. 2a). To measure the intertuberous distance, a para-axial plane was chosen to show both ischial tuberosities (Fig. 2b). To measure the midpelvic distances, i.e. the interspinous distance and the sagittal diameter at the level of the ischial spines – which represents the narrowest sagittal diameter in the pelvis – the plane was adjusted to show the inferior inner edge of the symphysis and both ischial spines (Fig. 2c). A midsagittal plane was used to measure the obstetric conjugate from the sacral promontory to the upper inner edge of the symphysis and the sagittal outlet from the inferior inner edge of the symphysis to the caudal end of the sacrum (Fig. 2d). The fact that the symphysis consists of collagen and has a smaller diameter than the adjacent bone usually required a minimal shift to a slightly paramedian plane. In a third approach, 3D volume-rendered images of the same 1-mm slices were evaluated with a technique that implies measurements in standard cranial, posterior and lateral views: The transverse diameter of the inner pelvis was measured on the 3D image from a cranial view (Fig. 3a). On a posterior view, the interspinous distance was measured as the shortest distance between both ischial spines, and the intertuberous distance was measured as the widest distance between the ischial tuberosities (Fig. 3b). Then, the data set was cut in midsagittal direction, and sagittal measurements were obtained on a strict lateral view. These included the obstetric conjugate as the shortest distance between promontory and symphysis, the sagittal outlet as the distance between the inferior inner aspect of the symphysis and the distal end of the sacrum, and the midpelvic sagittal diameter from the

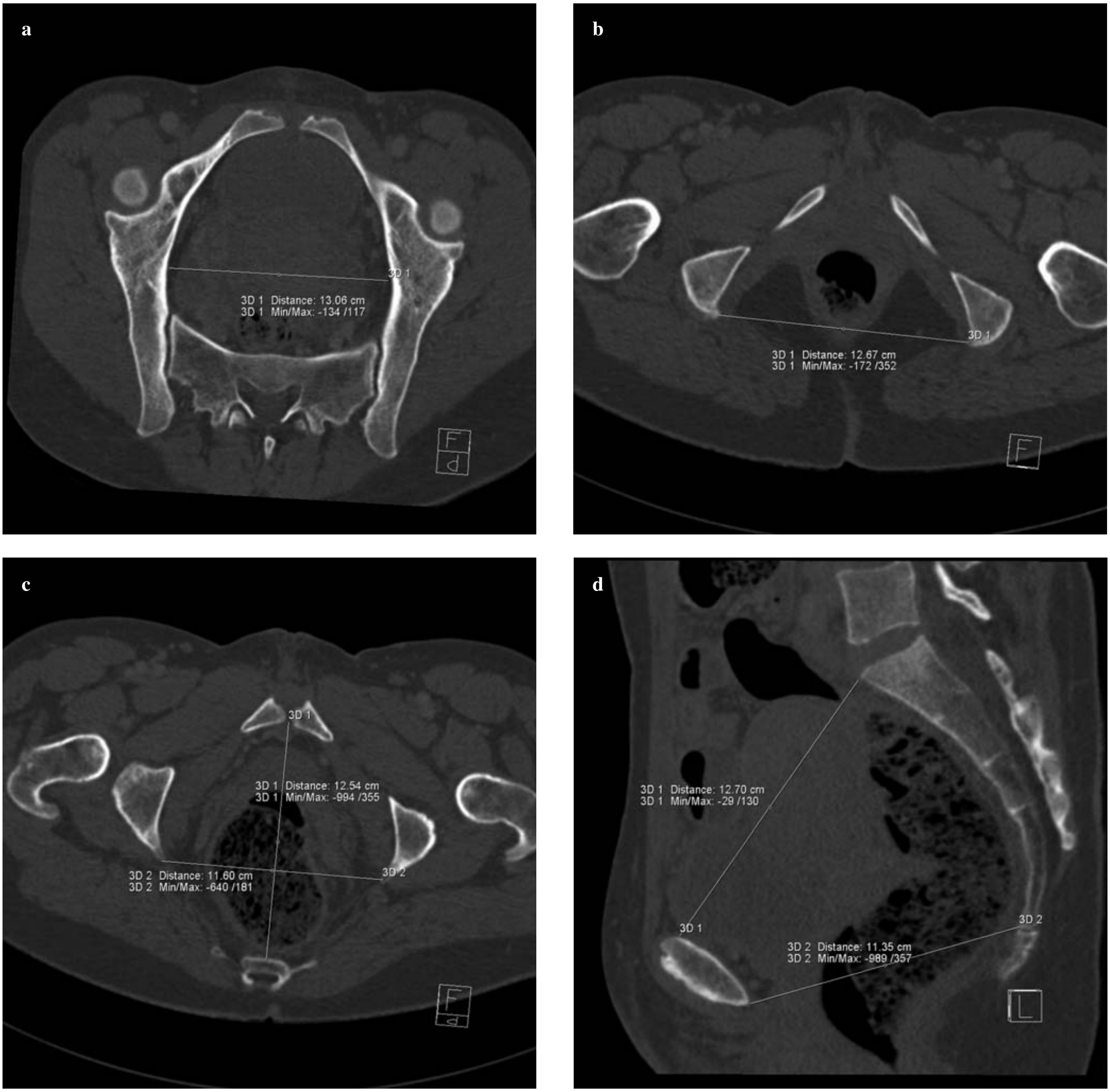

Fig. 2a Para-axial reconstruction showing the pelvic inlet. *Line* indicates the transverse inlet diameter. **b** Axial slice showing ischial tuberosities and the corresponding measurement. **c** Para-axial reconstruction showing ischial spines, the caudal end of the symphysis and the sacrum so that interspinal distance and sagittal midpelvic diameter can be measured. **d** Sagittal reconstruction showing the symphysis and the sacrum. *Lines* indicate obstetric conjugate and sagittal outlet diameter.

Fig. 2a *Ricostruzione para-assiale che mostra l'area interna della pelvi. La linea indica il diametro traverso interno.* ***b*** *Scansione assiale che mostra le tuberosità ischiatiche e la misura corrispondente.* ***c*** *Ricostruzione para-assiale che mostra le spine ischiatiche, la regione caudale della sinfisi e il sacro così da poter misurare la distanza tra le spine ed il diametro intermedio della pelvi.* ***d*** *Ricostruzione sagittale che mostra la sinfisi ed il sacro. Le linee indicano la coniugata ostetrica ed il diametro sagittale esterno.*

inferior inner aspect of the symphysis along the plane of the spinous process to the sacrum (Fig. 3c). As a fourth method, the same reconstructions were done based on 5-mm-thick slices, and all measurements were obtained equally on 3D volume-rendered images.

To assess clinical usability in daily routine, we clocked the times needed to measure all six pelvimetric numbers needed for pelvimetry by the different methods. To assess measurement error and interobserver variability, each data set was analysed independently by two blinded observers.

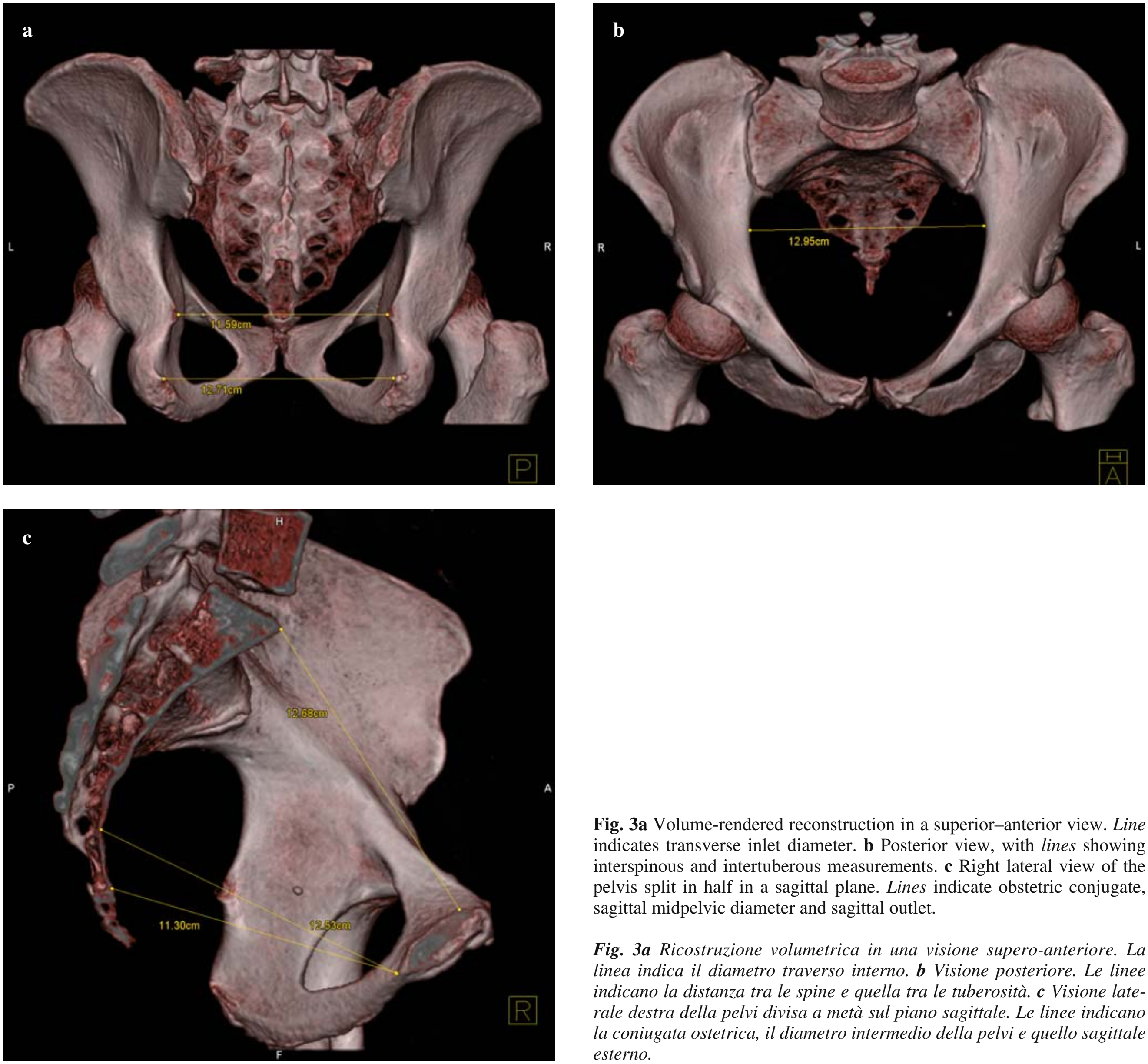

Fig. 3a Volume-rendered reconstruction in a superior–anterior view. *Line* indicates transverse inlet diameter. **b** Posterior view, with *lines* showing interspinous and intertuberous measurements. **c** Right lateral view of the pelvis split in half in a sagittal plane. *Lines* indicate obstetric conjugate, sagittal midpelvic diameter and sagittal outlet.

Fig. 3a *Ricostruzione volumetrica in una visione supero-anteriore. La linea indica il diametro traverso interno.* ***b*** *Visione posteriore. Le linee indicano la distanza tra le spine e quella tra le tuberosità.* ***c*** *Visione laterale destra della pelvi divisa a metà sul piano sagittale. Le linee indicano la coniugata ostetrica, il diametro intermedio della pelvi e quello sagittale esterno.*

Statistical Analysis

All continuous variables are displayed as mean and standard deviation (SD). Statistical tests were calculated using MedCalc software (MedCalc, Mariakerke, Belgium). p values <0.05 were considered statistically significant.

Agreement of the different pelvimetric measurements was compared for the different methods of acquisition, reconstruction and postprocessing. For this purpose, Bland-Altman analysis was performed [12]. This integrates the assessment of mean values, mean differences, SDs and limits of agreement to quantify the agreement between different continuous variables, i.e. between measurements of pelvimetric dimensions by two observers.

Results

Ex vivo CT pelvimetry agreed well with manual measurements, with a maximal deviation of 2 mm for the intertuberous distance and errors of 0–1 mm for the other pelvimetric distances, indicating that there is virtually no relevant systematic error. In vivo, interobserver agreement was best for assessing 3D volume-rendered images reconstructed from 1-mm slices with a correlation coefficient of 0.98, an SD of 1.8% and limits of agreement at –3.1% and +3.3% (Table 1). Interobserver agreement of the 3D assessment based on 5-mm-thick slices was very good, with a correlation coefficient of 0.95 and limits of agreement –5.6 and +5.2 %. With the 2D approach, a very similar interobserver

Table 1 Inter observer variability of pelvimetric measurements acquired with the four different approaches, indicated by mean difference, standard deviation, limits of agreement and correlation coefficient

Tabella 1 *Variabilità interosservatore delle misure pelvimetriche acquisite con quattro diversi approcci, indicata dalla differenza media, dalla deviazione standard, dai limiti di concordanza e dal coefficiente di correlazione*

Method	Mean difference (%)	Standard deviation (%)	Limits of agreement (%)		Correlation coefficient
Topogram	0.4	5.2	–9.7	+10.5	0.86
2D 1-mm slices	0.4	2.4	–4.2	+5.0	0.96
3D 1-mm slices	0.1	1.8	–3.1	+3.3	0.98
3D 5-mm slices	–0.2	2.8	–5.6	+5.2	0.95

Table 2 Correlation coefficients of the interobserver variability of different pelvimetric distances measured with different methods

Tabella 2 *Coefficienti di correlazione della variabilità interosservatore delle varie distanze pelvimetriche misurate con diversi metodi*

Method	m	c	h	q	i	s
Topogram	0.68	0.78	0.35	0.56	0.68	0.64
2D 1-mm slices	0.98	0.99	0.88	0.93	0.90	0.99
3D 1-mm slices	0.97	0.99	0.96	0.97	0.98	0.99
3D 5-mm slices	0.93	0.99	0.91	0.96	0.89	0.95

m, obstetric conjugate; *c,* transverse inlet; *h,* interspinal distance; *q,* sagittal midpelvic outlet; *i,* intertuberous distance; *s,* sagittal outlet

Table 3 Interobserver variability of pelvimetric measurements acquired with the 2D cross-sectional or the 3D volume-rendering approaches

Tabella 3 *Variabilità interosservatore delle misure pelvimetriche acquisite con metodica bidimensionale o tridimensionale-volumetrica*

Pelvimetric distance	Abbreviation	Length (cm)	Mean difference (%)	Standard deviation (%)	Limits of agreement (%)		Correlation coefficient
Obstetric conjugate	m	11.8 ± 0.2	–0.2	1.5	–3.1	+2.6	0.96
Transverse inlet	c	12.9 ± 0.1	0.8	1.0	–1.2	+2.8	0.99
Interspinal	h	10.8 ± 0.3	–1.2	2.9	–7.1	+4.5	0.91
Sagittal midpelvic	q	12.6 ± 0.2	0.2	1.5	–2.8	+3.1	0.96
Intertuberous	i	12.2 ± 0.4	1.0	3.4	–5.7	+7.7	0.91
Sagittal outlet	s	12.0 ± 0.2	0.2	1.8	–3.4	+3.6	0.96

m, obstetric conjugate; *c,* transverse inlet; *h,* interspinal distance; *q,* sagittal midpelvic outlet; *i,* intertuberous distance; *s,* sagittal outlet

variability was achieved, with a correlation coefficient 0.96. The topogram-based pelvimetry showed a much higher interobserver variability, with a correlation coefficient of 0.86, an SD of 5.2% and limits of agreement at –9.7% and +10.5%.

Regarding assessment of the different pelvimetric distances with the different methods in detail, SDs of interobserver variability were generally lower for cross-sectional and 3D approaches compared with the topogram-based measurements (Table 2).

Also, variability was lower for obstetric conjugate (m), transverse inlet (c), sagittal midpelvic (q) and sagittal outlet (s) than for interspinal (h) and intertuberous (i) distance. Regarding the different pelvimetric distances in summary, interobserver variability of 2D and 3D measurements was very low, with an SD <2% for m, c, q and s distances, whereas variability was higher for h and i (Table 3).

CT dose index ranged from 11 to 15 mGy at standard tube voltage of 120 kVp and a reference tube current time product of 220 mAs(ref) with automatic exposure control, resulting in tube current values of 142–180 mAs. Thus, based on a conversion factor of 0.017 mSv/mGy*cm and an average scan length of 25 cm for CT pelvimetry, the calculated equivalent dose amounted to 5.5 mSv on average. With a low-dose protocol and reference tube current time product of 83 mAs(ref), an index of 3.1–4.8 mGy and an equivalent dose of 1.7 mSv were achieved.

Interobserver variability was comparable for normal and low-dose protocols (overall coefficients 0.96 and 0.95, without significant differences). The impression was that a further reduction of tube current would be possible if the assessment of pelvic dimensions is the only purpose of the exam.

Regarding reading time for measuring the various pelvimetric dimensions, there were significant differences between the different postprocessing approaches. The topogram-based approach was performed fastest, with an average reading time of 120±30 s, whereas the 3D methods required 186±24 and 180±15 s for 1-mm and 5-mm data sets, respectively. Assessment of 2D methods was most time consuming, with a reading time of 342±78 s.

Discussion

CT-pelvimetry offers anatomically exact measurement of the bony pelvis and is therefore a useful means of determining pelvimetric measurements, especially as interobserver variability is low. In comparison with the interobserver variability reported for standard MRI pelvimetry in literature [13], CT offers an at least comparable accuracy. Our results indicate that a very easy, fast and accurate determination of pelvimetric dimensions can be achieved with 3D volume-rendered reconstructions, which therefore can be regarded as the method of choice. Although the best accuracy is achieved with this approach, measurements on volume-rendered images derived from 5-mm-thick slices achieve a comparable agreement as 2D cross-sectional reconstructions from 1-mm data sets. With a standard deviation of 2% corresponding to 2–3 mm for most pelvimetric distances, the accuracy of these 2D and 3D measurements seems acceptable, whereas the SD of interobserver variability for the topogram-based assessment with about 5% SD may be clinically relevant. However, clinical studies integrating the performance of pelvimetric indices in predicting dystocia are needed to draw definite conclusions regarding the clinically required accuracy.

Not all pelvimetric values show the same interobserver variability. As described for MRI pelvimetry [13], the intertuberous distance and the sagittal outlet diameter have a slightly higher measurement error. The round shape of the ischiadic tuber and the continuous transition between the spinous process and the ligaments inserting there with variable density and calcification can be assumed to represent the reasons for this difference [14].

Our data also confirm a sufficient diagnostic accuracy for low-dose CT scans. Still, taking into account the availability of MRI as an alternative method without ionising radiation, the indication for CT pelvimetry is very limited, especially in pregnant women [15]. Regarding the fact that dystocia can be life threatening for mother and foetus, CT may still represent an adequate diagnostic tool in critical situations if MRI is not readily available or is contraindicated for other reasons, or in nonpregnant women with a history of dystocia.

Altogether, very precise pelvimetric measurements can be acquired in CT and can be used for retrospective analyses on existing data. Also, the results should apply similarly to MRI data sets acquired with 3D pulse sequences (e.g. VIBE), which would release dependence on a precise primary data acquisition.

Conclusions

CT pelvimetry offers a precise diagnostic imaging modality with very low interobserver variability. Three-dimensional postprocessing makes easy, fast and accurate assessment feasible. Low-dose protocols do not significantly affect accuracy and can contribute to significant dose savings, although radiation exposure may restrict the prospective application of CT pelvimetry in general. However, the results also apply for retrospective analyses. In particular, information regarding anatomical bony pelvic measurements in combination with clinical data on birth outcome can lead to a better understanding for cephalopelvic disproportion.

Conflict of interest statement The authors declare that they have no conflict of interest to the publication of this article.

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